

Lambda-Dominated

Universe

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or... Why Teach Kids Cosmolog

A talk given at the Aspen Center for Physics

July 6 2004



Cosmology is a story of the intense excha between theory and observation

• It involves adventure and imagination and incorporates both basic physics as well as modern technology

·It is fascinating and fun!

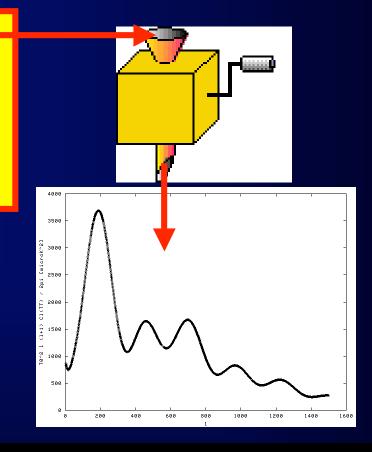
· We are on the frontiers of a new

Tools:

Image Processing Summand from the from the Access Astronomy Project Penote Access Astronomy Project Physics Department

to analyze digital im

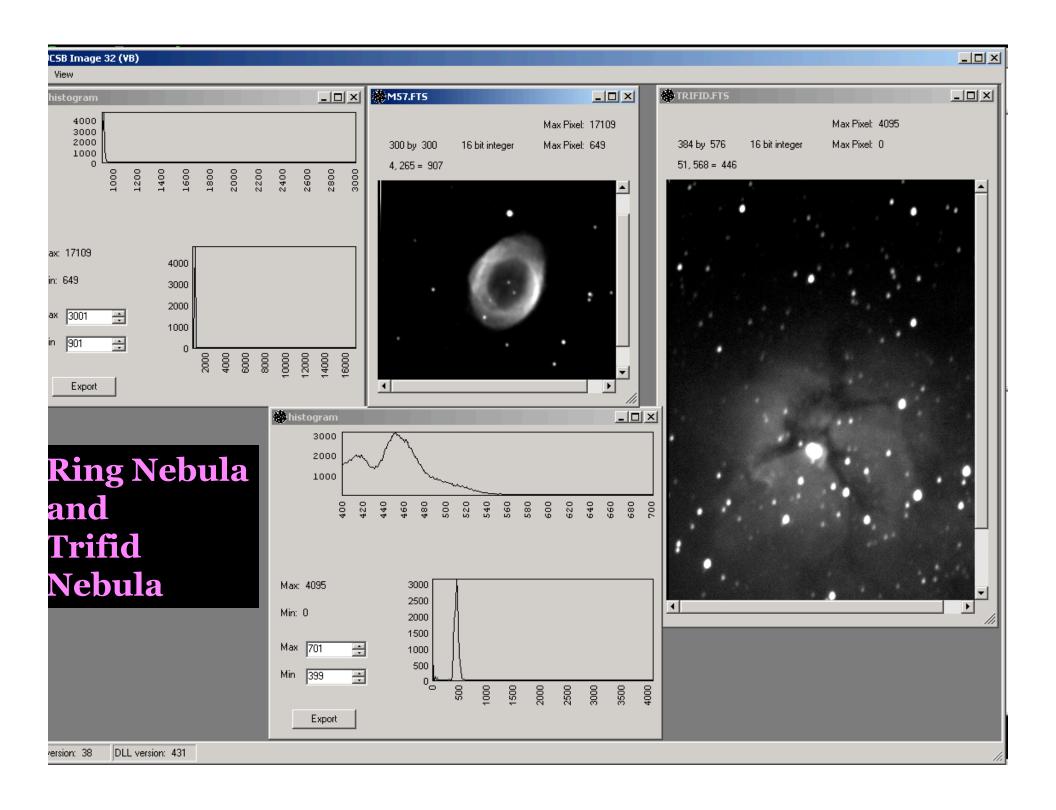
$$\begin{split} &\Omega_b \; \Omega_{cdm} \; \Omega_{lambda} \\ &\Omega_{neutrino} \\ &H_0 \; \text{initial conditions,} \\ &\text{ionization, k, T_{CMB} ...} \end{split}$$

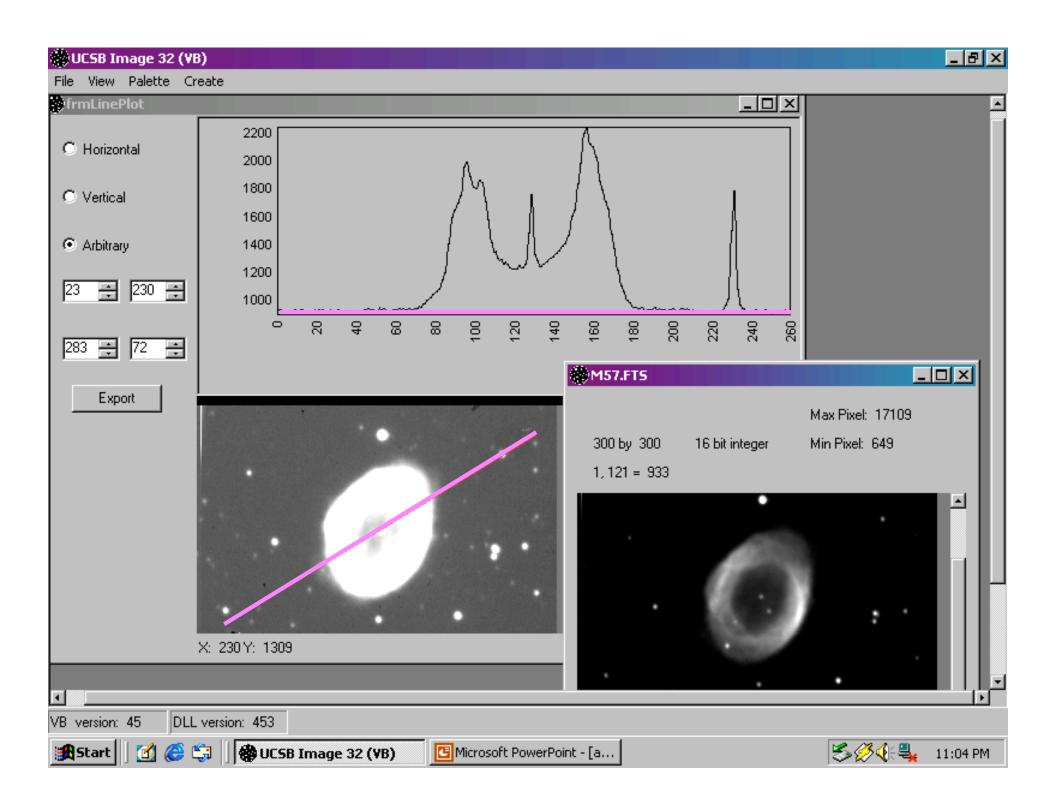


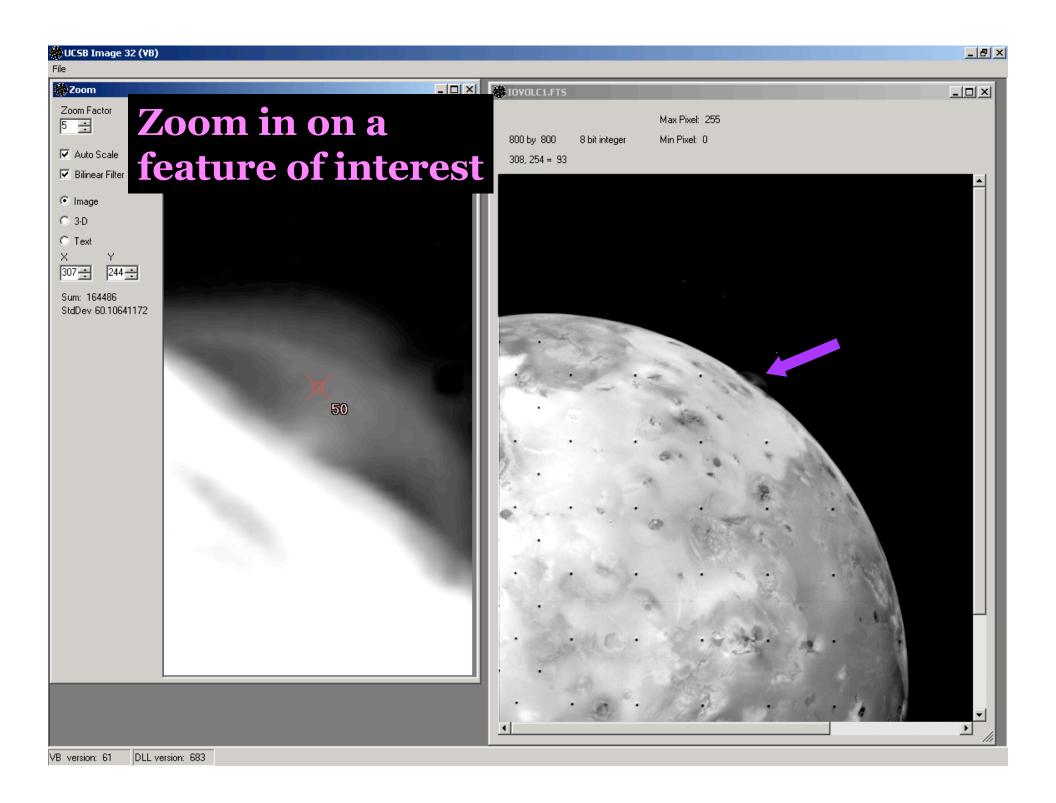
CMBFAST now available ON LINE, in REAL TIME, to model the power spectru of the CMB

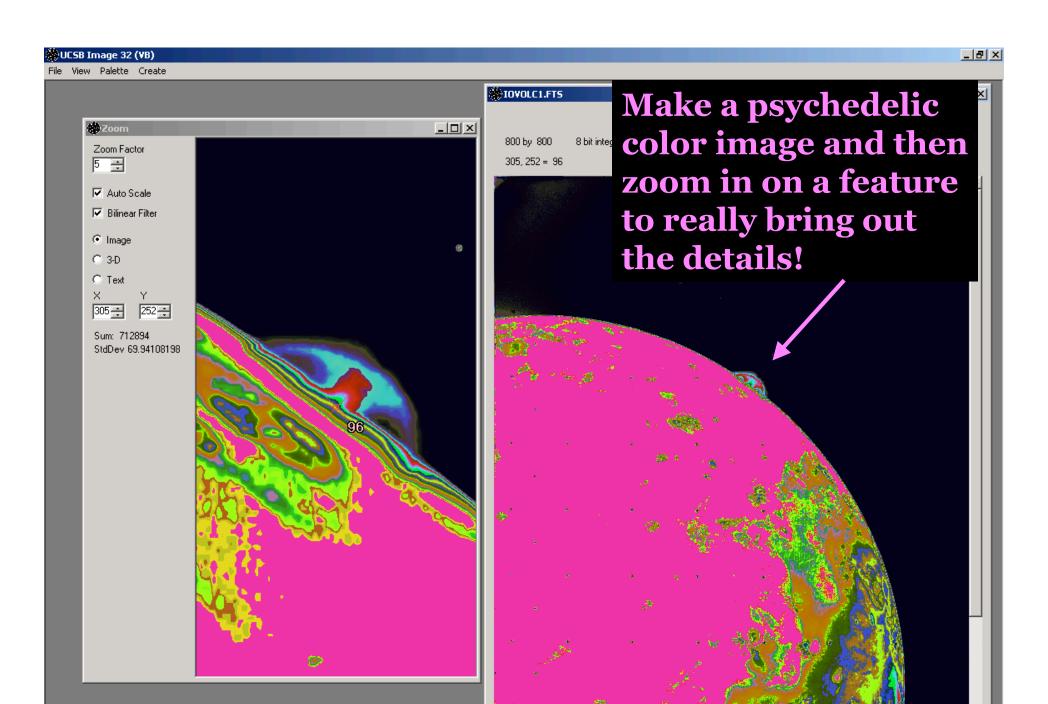


Digression for a shameless plug of our FREE software and supp curricula which are available on http://www.physics.ucsb.edu/~j

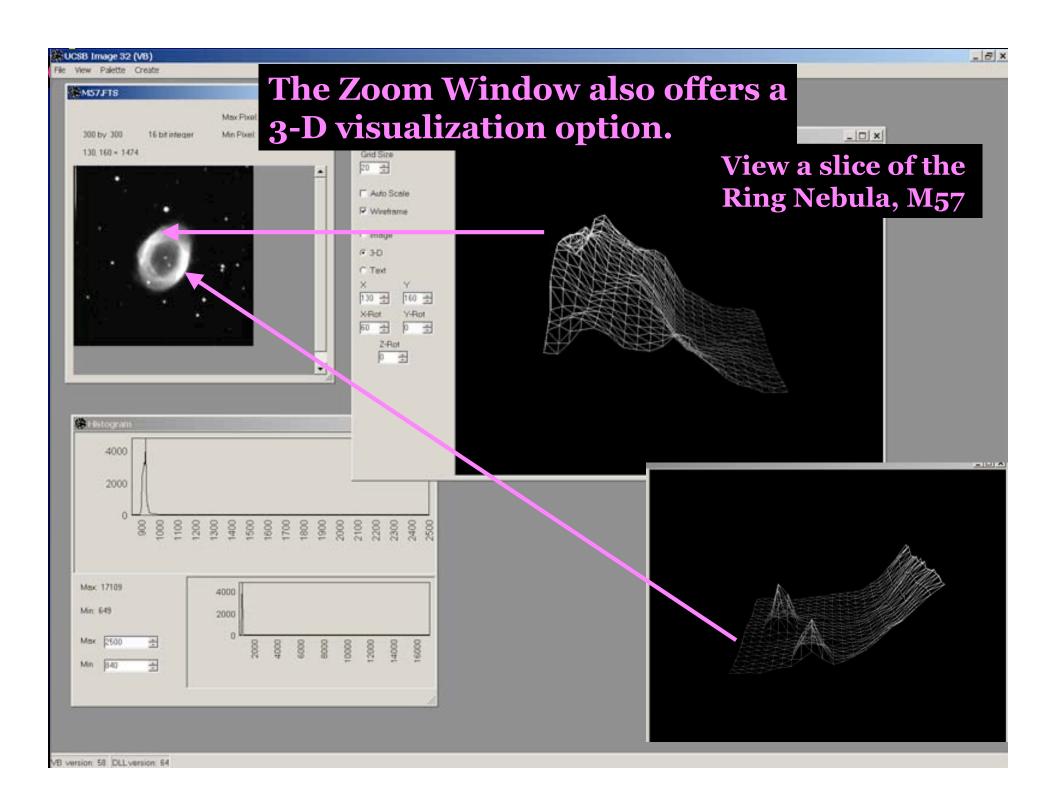


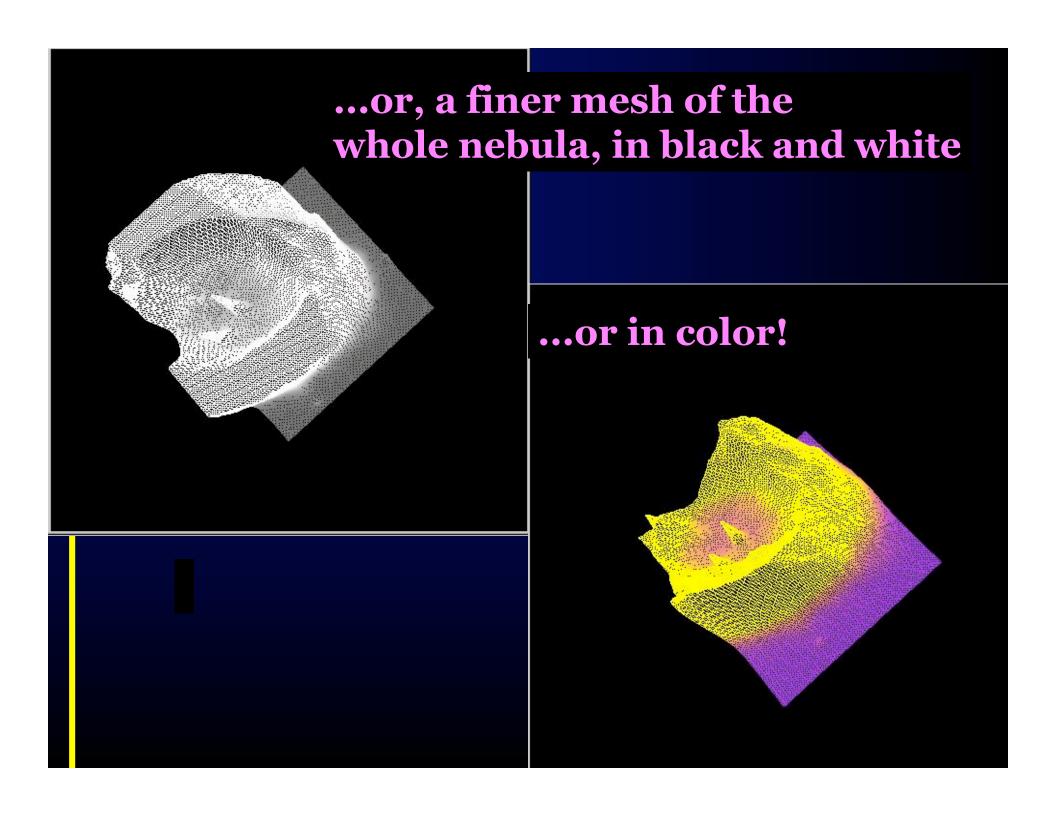


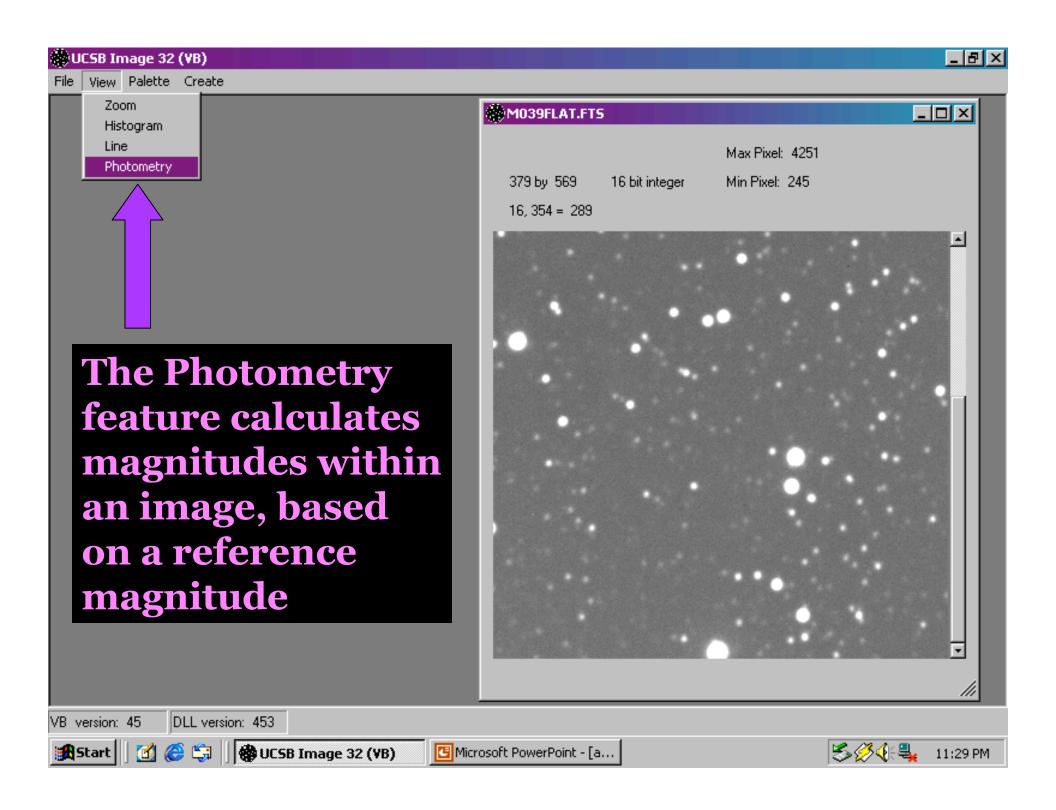


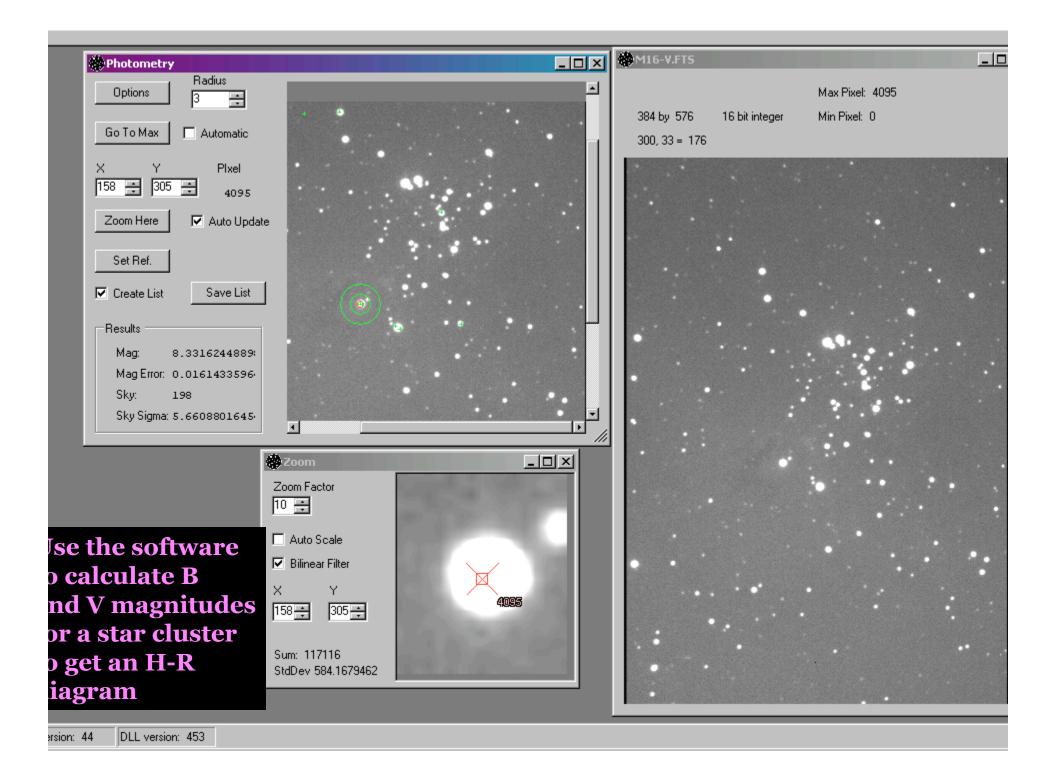


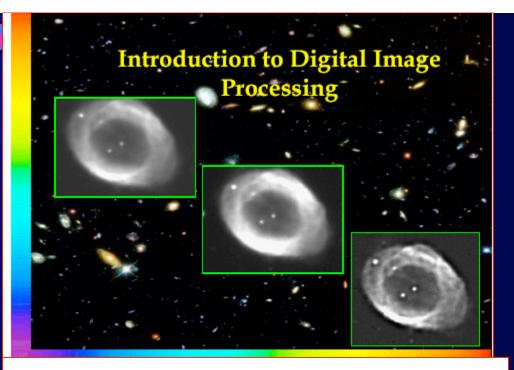
VB version: 61 DLL version: 683





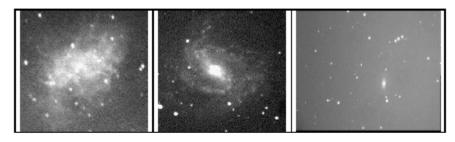






RAAP Image Processing Curricula for High School and College Physics and Astronomy

Finding Light Curves of Supernovas using RAAP CCD Images



Jatila van der Veen Remote Access Astronomy Project, Physics Department, University of California, Santa Barbara revised: August, 2003

Data: Mark Parker and Shea Lovan, UCSB Physics Department

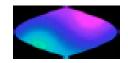
Images for this lab can be downloaded from the RAAP home page: http://www.deepspace.ucsb.edu. RAAP Decays Processing Curvinsia for High School and Callege Physics and detrooping

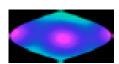
COBE for (BIG) KIDS:

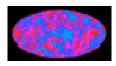
Discovering how the smults of the

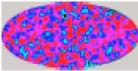
COSMIC BACKGROUND EXPLORER SATELLITE help us understand the early

UNIVERSE









Satisfa neur efer Since.

REMOTE ACCESS ASTRONOMY PROJECT PHYSICS DEPARTMENT, UNIVERSITY OF CALIFORNIA, SANTA BARBARA

> Plant with markagest, (1907) Sentent August, 2007 Discovering how the negative of the

BCoppetated 2004, Corner des Tross

http://www.physucsb.edu/~jatila



Back to the topic of Cosmology:

Standard Cosmological Model of the 20th cent was founded on three observational pillars: 1) the red shifts of galaxies, 2) the abundances of light elements, and the 3) cosmic microwave background radiation.

and the theoretical framework of General Relativity

- igspace nothing can travel faster than light in a vacuul
- matter and energy are equivalent
- + space and time are not separable
- matter and energy determine the geometry of



The first clue that the universe was expanding Hubble's observation of the red shifts of gala

Edwin Hubble



$$\frac{\lambda' - \lambda_0}{\lambda_0} = z$$

Red shift

$$\frac{500-400}{400} = .25 = Z$$

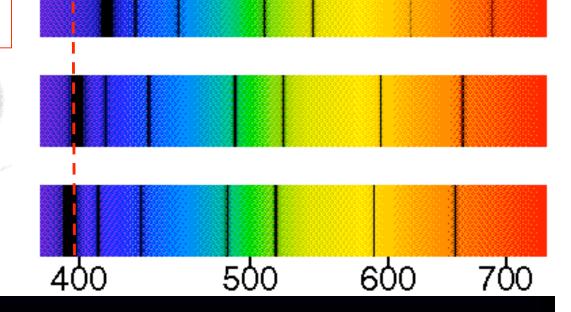
Classically:

$$\frac{\Delta\lambda}{\lambda} = z \approx \frac{v}{c}$$

so v = .25c



near by gala



500

600

7Q0

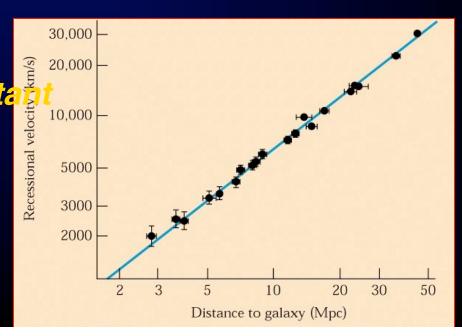


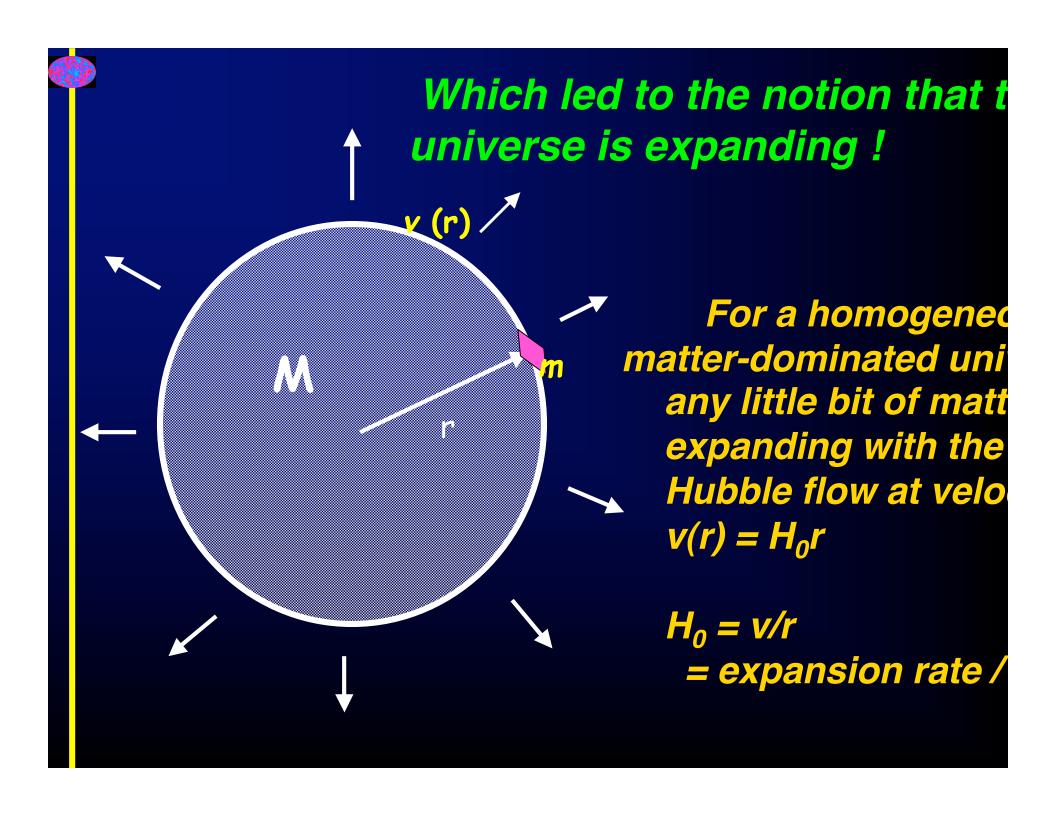
This led Hubble to his "Law":

$$v(r) = H_0 r$$

The recession velocity of a galaxy proportional to its distance from the second second

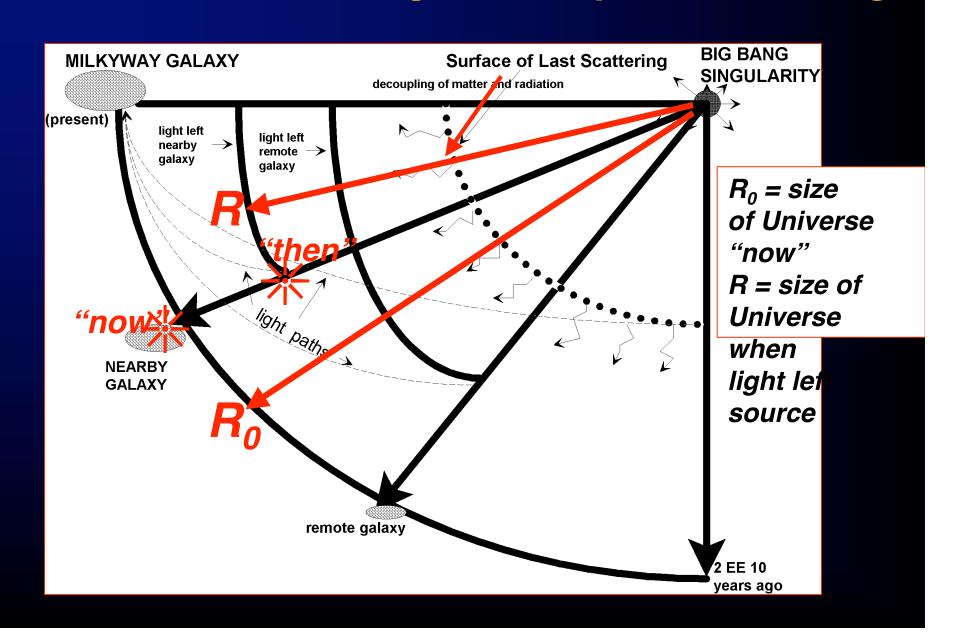








But because looking out in space = looking b





...the red shift <u>really</u> tells us about the stretching of the wavelengths of light due to the expansion of the Universe:

$$\frac{\Delta\lambda}{\lambda} = z = \frac{R_0}{R} - 1$$

So H₀ gives us the ratio of the <u>present</u> ansion rate to the present size of the Unive

H "now"

$$H_0 = \frac{\dot{R}}{R_0}$$

rate of change of "size" of

"size" of universe "now"

The value of H₀ puts an <u>upper</u> limit on the age of the

In the Standard Middesof the 20th Century,

 $H_0 = 50$ km/sec/Mpc, putting the maximum age of

$$H_0 = \frac{50km}{\sec \cdot Mpc} = 50 \times 3.24 \times 10^{-20} \sec^{-1}$$

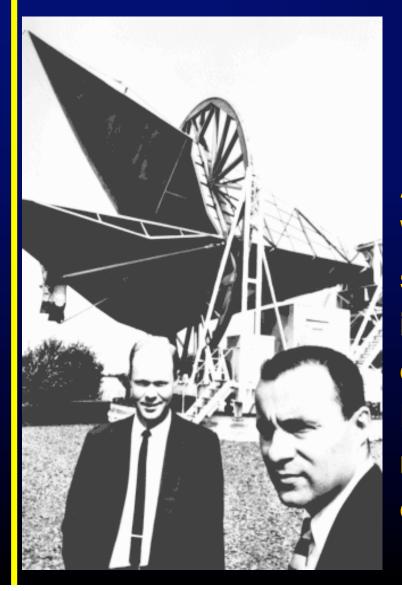
$$H_0 = 1.68 \times 10^{-18} \,\text{sec}^{-1} \approx \frac{1}{t}$$

$$\therefore t \approx 1.96 \times 10^{10} \, yrs$$

years

f the

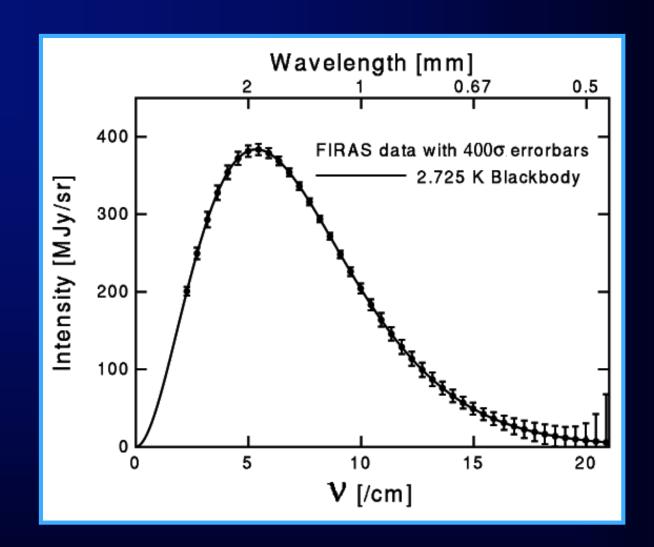
The Big Bang nucleosynthesis and abundances of light elements were predicted by Figure 1948 Ph.D. thesis.



And in 1964 Arno Penzias and Rober Wilson, then at Bell Labs, noticed a small discrepancy in their microwav instruments that indicated an excess of radiation coming in from space. Not content to ignore it, they soon made one of the profound discoverie of the 20th century:..

They had found the after glow of the enormous heat left over from the "BIG BANG".



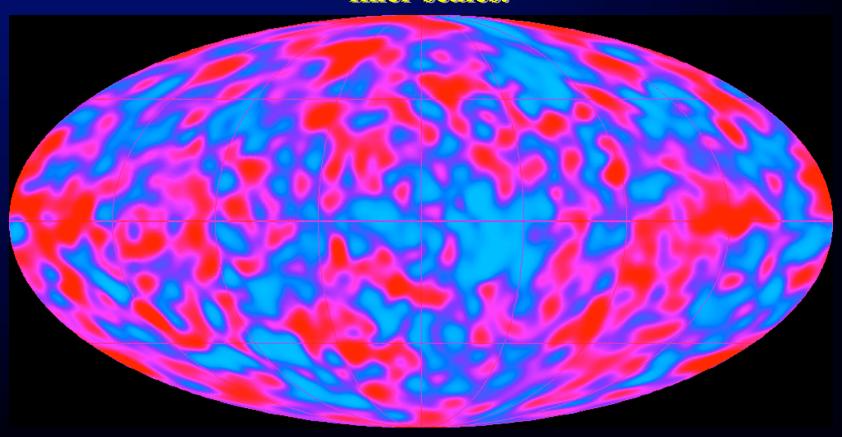


which fit a perfect "black body" spectrum



In 1992, data from the Cosmic Background Explorer satellite, launched by NASA in 1989, showed evidence for minute temperature variations (anisotropy) in the CMB at a level of just one part in 10⁵, at angular scales around 10° or so and

in the last decade these have been measured at increasingly finer scales.

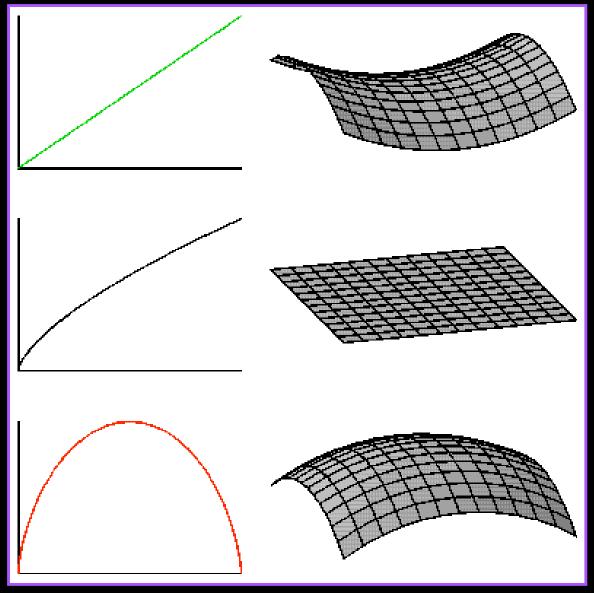




So the question then was: will the universe expanding forever or will it eventually collaback on itself?

The answer to this depends on the total matter and energy density of the universe.

Is the universe open - flat - or closed?



open?

expansion energy >
gravitational potential
energy

flat?

expansion energy =
gravitational potential
energy

closed?

expansion energy <
gravitational potential
energy



The dimensionless density parameter of the universummarizes the overall content of the Universe:

$$\Omega = \frac{\rho_{total}}{\rho_c} = 1$$

Where ρ_{total} = total average density of the all the component considered at sufficiently large scales to look homogeneous critical density necessary for a flat universe.



To make a long story short Ω should have the following components:

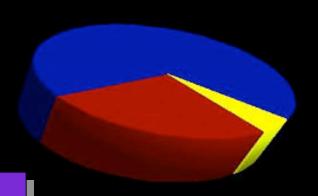
$$\Omega_{total} = \Omega_{baryon} + \Omega_{darkmatter} + \Omega_{\Lambda} = 1$$

mass/energy density of all gravitating matter

energy density of "lambda" - Einstein's cosmological constant



We now have good reason to believe that most of the mass-energy of the Universe is in some form that we can't even see!



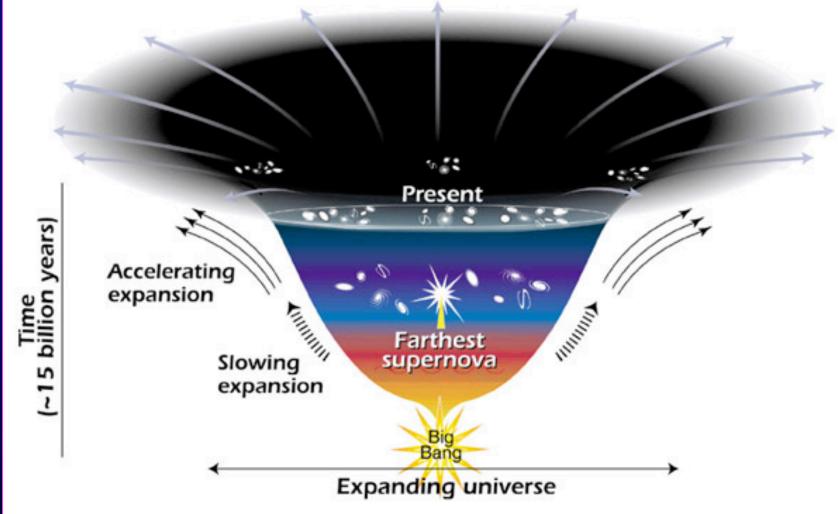
drawing shamelessly plagiarized from Sean Carroll Dark Energy

Dark Matter

Ordinary

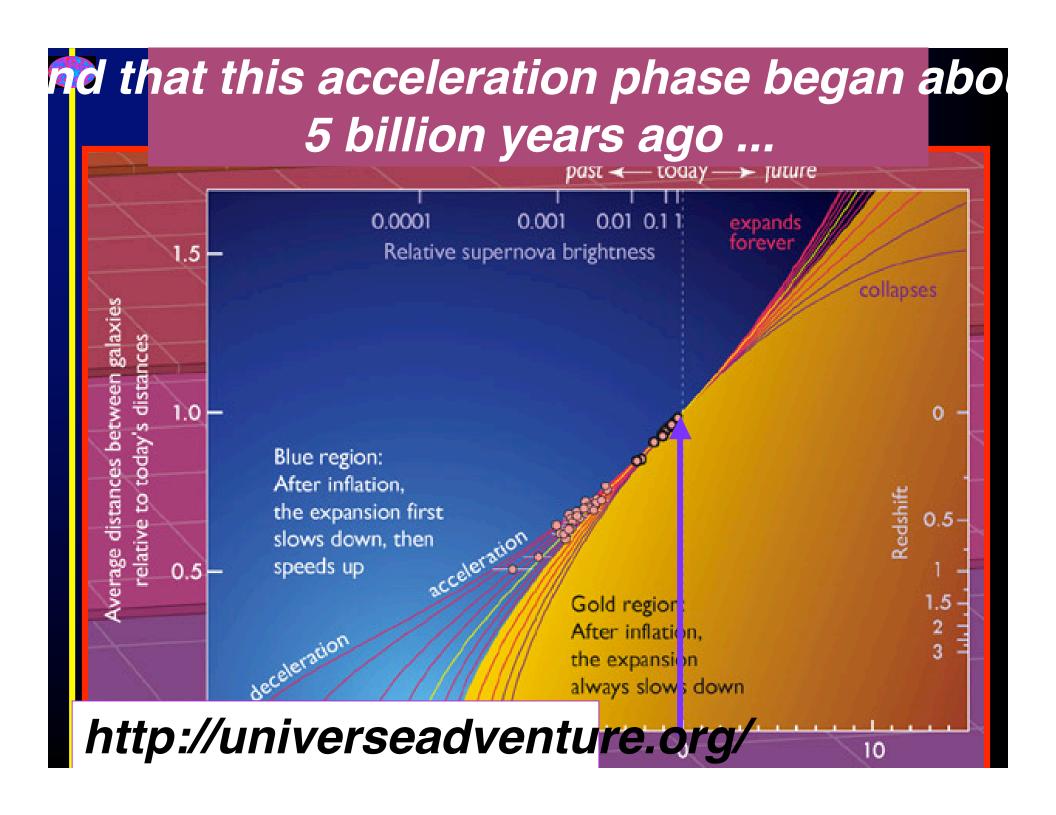
Matter





NASA/A. Riess

...AND we now have evidence that





We need a new cosmological mode Standard Cosmological Model of the 21st Century

- * The mass/energy of the Universe is dominated by which may be a cosmological constant, but may all other form of "dark energy" which varies over time
- * The expansion rate is increasing, and this accele have begun about 5 billion years ago.
- * The age of the universe is 13.7 billion years.
- * The geometry of the universe still appears to be to as we can see back in time.



Three Observational Pillars of the Lambda-dominated Cosmological

1. High – redshift type la Superno

2. Accurately determined Power spot of the CMB

3. Ages of Globular Clusters



How do these observations support the model?

Accelerating universe High - z Sne

Geometry of universe istribution of temper anisotropies in the CN

Age of the universe Ages of Globular Clus

And the Power Spectrum of the CMB anisotropies an independent way of confirming all the other ob and constraining estimates on ALL the cosmolog



LABS FOR A LAMBDA-DOMINATED UNIVERSE

Students use real, public domain data to follow the cosmologists use in deriving the model from observed

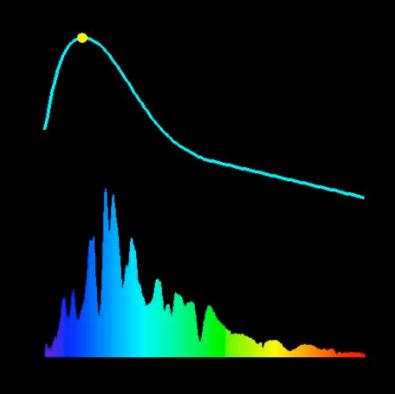
- 1. Students use light curves from high-Z type 1a supernovae to get absolute magnitudes, compare to red shift, and observe deviation
- 2. State in the the age of the oldest globular turnoff points on the HR Diagram to derive minimum the Universe which is consistent with the age of the
- 3. Students use CMBFAST to derive the CMB power spectrum from cosmological models and find the set of parameters that best fit the data.



Type 1a Supernovae are good Standard

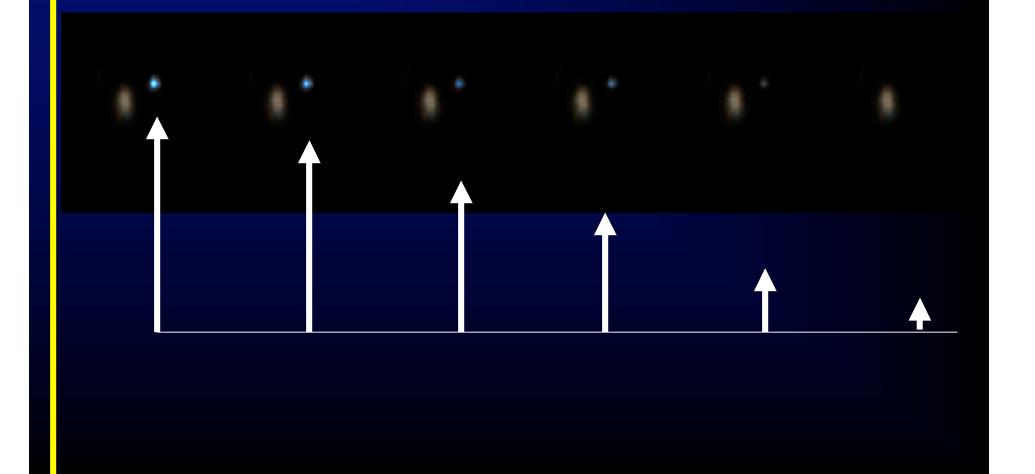
 $3 \times 10^{9} L_{\odot} < L_{peak} < 5 \times 10^{9} L_{\odot}$



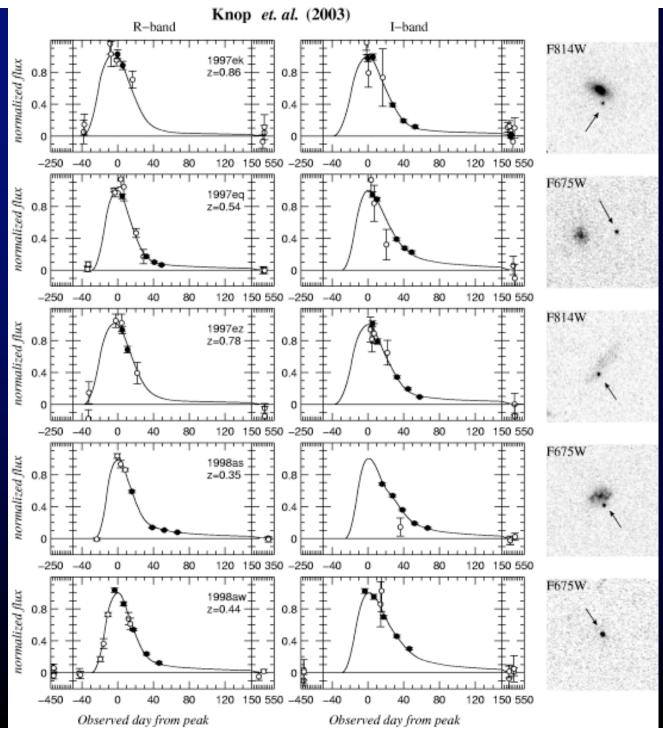




Using our software, students can do plon a series of images of supernovae are the light curve.



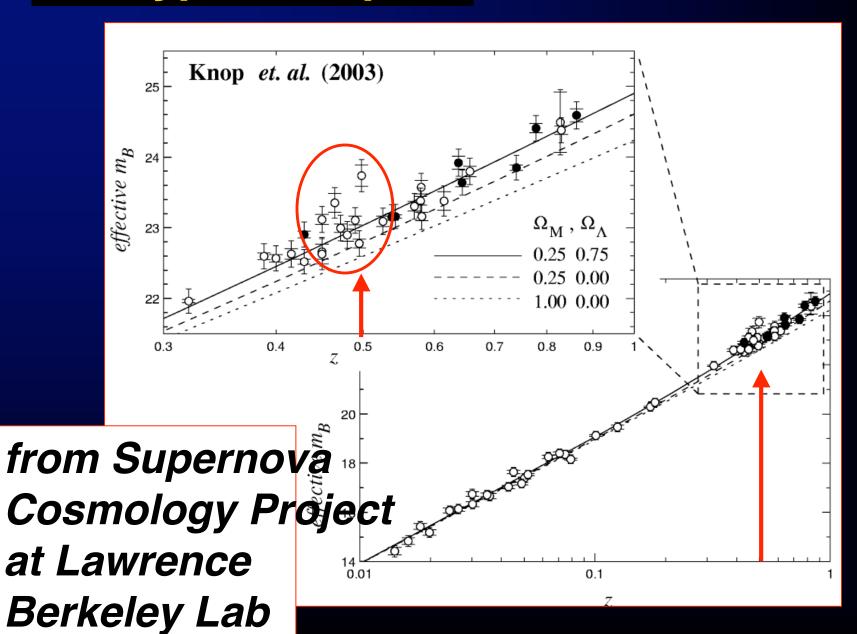




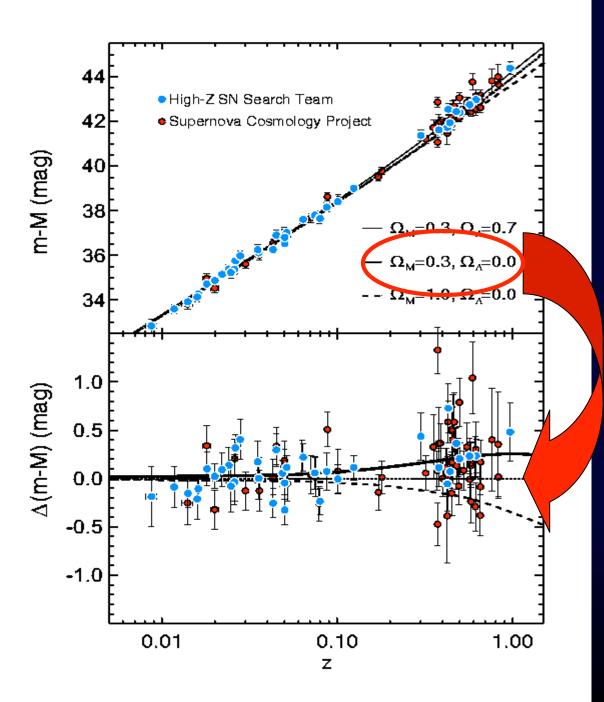
light curve from Knop et al., UC Berkel



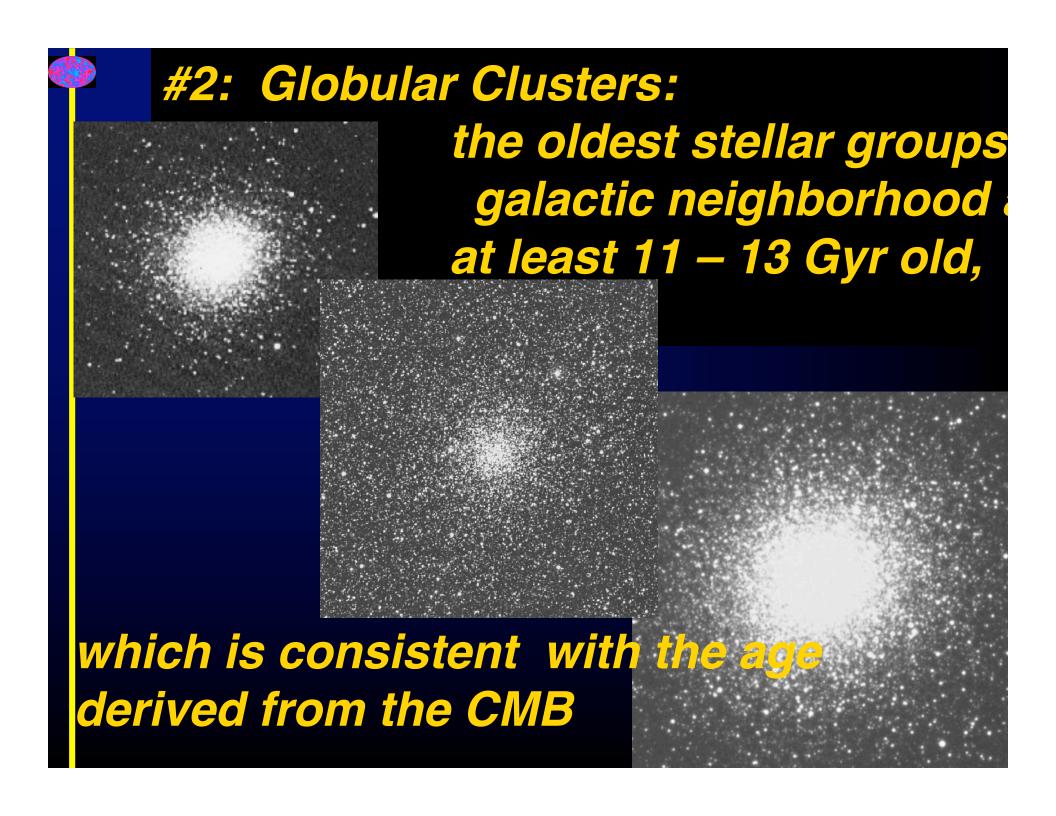
#1: Type la Supernovae

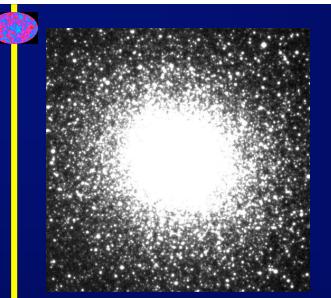






Flat slope in graph below is for no cosmolog constant; points are differences between predicted distances for not accelerating unit and observations



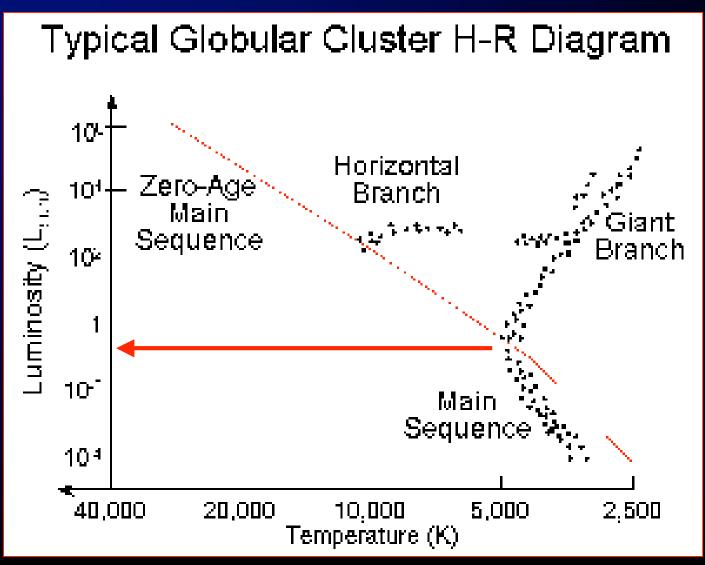


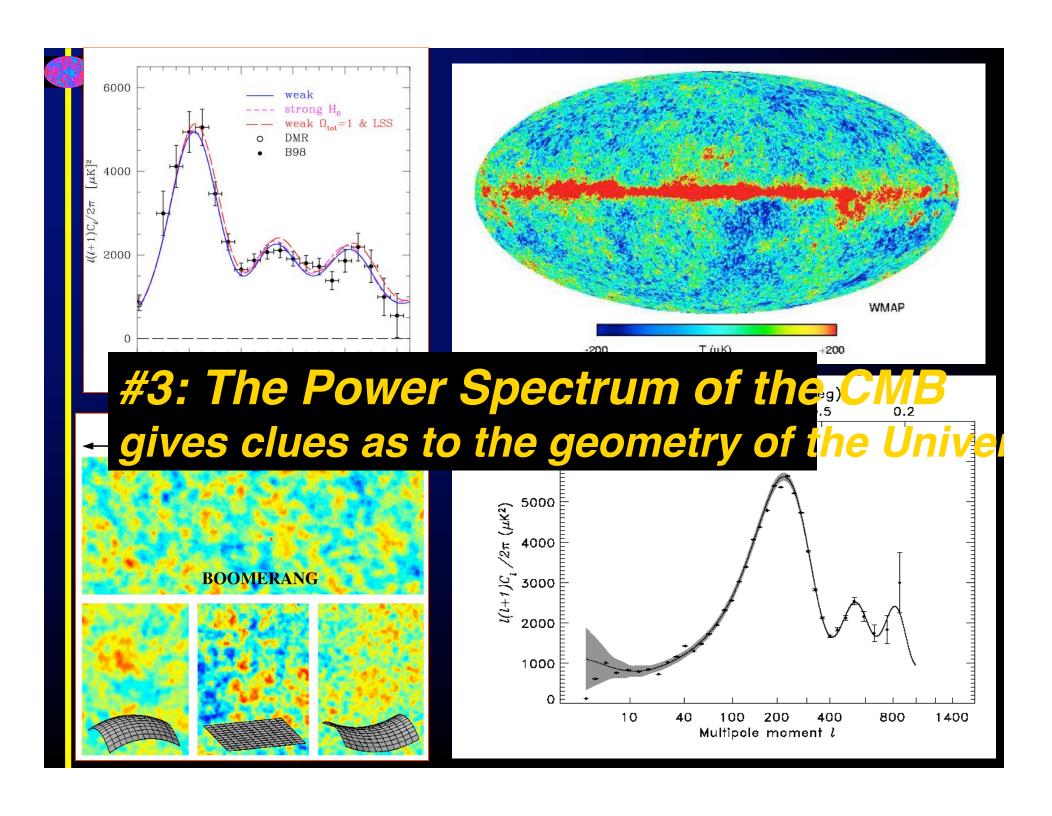
Using our software, studen do B-V photometry on stars associated with the oldest

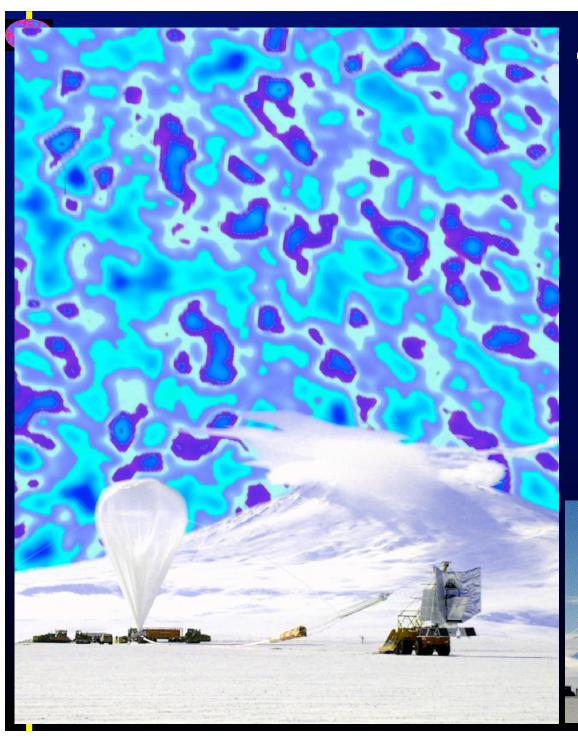
using HST images
that are now in the
public domain, to
obtain an H-R
diagram and find the age from the turn-o



Luminosity at turn off point gives approximation of age of cluster.





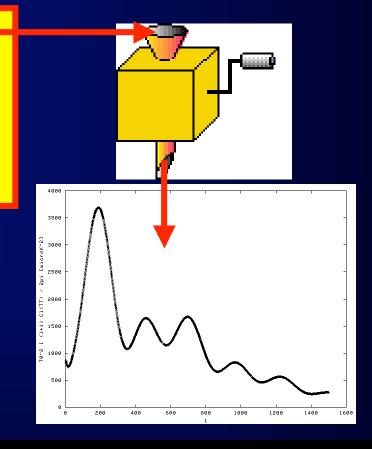


The sky at 150 GHz (~2 mm)

The sky at 545 THz (~550 nm)



$$\begin{split} &\Omega_b \; \Omega_{cdm} \; \Omega_{lambda} \\ &\Omega_{neutrino} \\ &H_0 \; \text{initial conditions,} \\ &\text{ionization, k, T_{CMB} ...} \end{split}$$



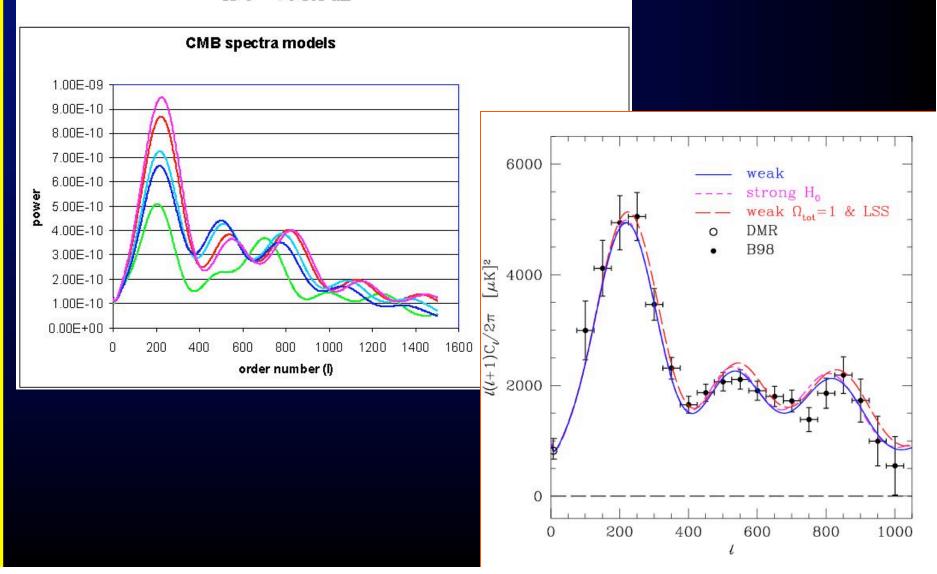
sing CMBFAST now available ON LINE, in REAL TIME, students can model the omposition and Geometry of the Universe

http://lambda.gsfc.nasa.gov/cgi-



and compare their models to the REAL

The effect of increasing Ω_b and decreasing Ω_{cdm} with $\Omega_{Lambda}=.7$ H-0 = 70 for all





in progress:

